JOINT INVOVLEMENT AND MOVEMENT AMPLITUDE IN TWO-SEGEMENT MOVEMENTS

A Senior Scholars Thesis

by

ABBY LYNN DUDENSING

Submitted to the Office of Undergraduate Research
Texas A&M University
In partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2007

Major: Kinesiology

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Research Advisor: Caroline J. Ketcham
Associate Dean for Undergraduate Research: Robert C. Webb

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ABSTRACT

Joint Involvement and Movement Amplitude in Two-Segment Movements (April 2007)

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The purpose of this research is to identify the effect of varying constraints on the planning and organization of multijoint movements, specifically how amplitude and movement direction affect the planning and organization of a series of goal directed movements. Subjects were asked to move from one target to the next on cue as quickly and accurately as possible. Target sequences varied in distance between targets and direction. It was expected that the planning and organization of multijoint movements would be different depending on movement direction and movement amplitude requirements. Results show that movement durations were highest for long movements than for shorter and that peak velocity was higher in long movements.

DEDICATION

I dedicate this thesis to my parents Lynn and Renee Dudensing whose love and support of me allow me to strive to be my best.

ACKNOWLEDGMENTS

I would like to thank my research advisor Dr. Caroline Ketcham and Tiffany Rodriguez for guiding me through the research process and supporting me when I often doubted myself.

Thanks to the Texas A&M University and the Department of Kinesiology for excellent instruction and for opportunities that I have been honored to get. I would also like to thank all of the individuals who participated in this study.

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CHAPTER I

INTRODUCTION

In various studies, it has been shown that target size, movement amplitude, and joint coordination affect the planning and organization of both simple and complex joint movements (Fitts 1954; Rand et al. 1997; Dounskaia et al. 2002a; Dounskaia et al. 2002b; Ketcham et al. 2004). Target size and movement amplitude changes constitute changes in the accuracy demands of all movements. By changing the accuracy demands of a task, movement kinematics, are changed, suggesting a change in the motor planning features of that movement.

A very well used task to assess planning of movements as a function of complexity is a Fitts' task. In a Fitts' task, index of difficulty (ID) was changed by manipulating target size and amplitude. Two target sizes were placed given distances apart and the subject was asked to move their finger from target to target as quickly and accurately as possible. It was found that as index of difficulty (relating to target size and/or amplitude changes) increased, movement time also increased, showing that the brain required more time to prepare for a more difficult task (Fitts 1954).

In a related study, Smyrnis and colleagues (2000) looked at two dimensional pointing movements using a computer joystick. Subjects performed aiming movements on the

This thesis follows the style of Experimental Brain Research.

computer screen from a center target to a peripheral target. Target size, amplitude and direction were manipulated and found to affect movement parameters. As in Fitts' study the longer amplitude movements affected movement time. Evidence that target size and direction affect different and separate parts of movement execution was found. Direction affects the initial part of movement execution while target size affects the final part suggesting that movements are segmented.

To further Fitts' study, Thompson and colleagues (2007), looked at the effects of the combination of target size, movement amplitude, and orientation of a movement in the workspace on the kinematics of pointing movements. A point to point target task was performed with a mouse cursor on a computer screen. Target size was found to affect the final part or corrective portion of movements. However, distance did not affect the shape of the velocity profile. It was concluded that target size was a task constraint, movement amplitude was a task effector, but orientation showed characteristics of both (Thompson et al. 2007).

In yet another study the accuracy demand of a task was shown to effect movement parameters. Pegboard experiments where hole size varied in order to manipulate task difficulty were also performed (Milner and Ijaz 1990, Fitts 1954). Velocity profiles shifted from a smooth bell shaped trajectory to a more asymmetric shape as the hole size was decreased therefore increasing accuracy demands. Decelerative phases contained more submovements, demonstrating that the accuracy of that movement required a change in performance.

Movements are broken down into two phases, an initial adjustment phase that brings the movement into the vicinity of the target and the control phase that adjusts for the specific demands of that task (Woodworth 1899). The ability to perform a task accurately is described by submovements. More difficult tasks are marked by prominent submovements in a velocity profile while velocity profiles of simple tasks contain few sub movements. Difficult movements affect accuracy demands (Meyer et al. 1988; Ketcham et al. 2002; Wisleder and Dounskaia 2007).

Through studying of such factors as movement duration, velocity, and the deccelerative phases of movements, the speed accuracy trade off was confirmed although a wide variety of different tasks were performed. Movements with a longer distance were characterized by higher durations, higher peak velocities while more difficult movements with a short distance spent more time in the second decelerating phase.

Application of these findings applies to the study of two segment aiming movements. Changing ID in one segment of a multisegment task affects kinematic variables as previously seen; however, it also has an effect on the planning and control of the subsequent segment. In a series of studies, Rand et al. (1997) examined two segment aiming movements to determine whether the difficulty of the second segment influenced the characteristics of the first segment by manipulating target size. The conclusion to this study suggests that the planning of complex movements are based in part on the accuracy demands of multiple segments of the sequence (Rand et al. 1997). Furthermore, it was shown that planning and organization processes link the two segments together when the difficulty of the initial segment is low in relation to the second. This is shown by kinematic analysis; the constraints of the second segment affected the first. In contrast, when the accuracy constraints, and thus difficulty of the first segment were high, the segment interdependency disappeared. Two-segment movements were not linked together in this case (Rand and Stelmach 2000).

The study of mulitsegment movements furthers the understanding of how movements are specifically controlled by central planning processes. By including direction manipulations, movement planning processes can be understood in still a more complex manner. Direction changes allow for the analysis of the interactive torques of joints involved in movements. Because movements are affected by biomechanical constraints as well as by brain planning processes, it is important to include this important aspect. Studying planning and organization of movements must be coupled by biomechanical analysis of movement to bring validity to results (Ketcham et al. 2004). Joints act together in the execution of the action, one joint has an effect on another. This is due to muscles spanning multiple joints. Constraints on movements can also occur based on the type of joint involved or the plane that the movement is being performed in.

Dounskaia and colleagues (2002a) studied the influence of biomechanical constraints, more specifically joint coordination, on horizontal arm movements. They found that joint control is dependent on the role of the joint in a movement. One joint may serve as a leading joint providing overall power for the movement, while the other joints involved in the movement control fine motor. It was also found that the coordination of movements between two joints affects the biomechanical constraints on movement patterns (Dounskaia et al. 2002a). The shoulder is controlled in much the same way during all movements; however, the elbow required more specific regulation. Interactive torque assists or resists a movement making control of some movements more difficult.

Gribble and Ostry (1999) looked at the influence of interactive torques on single and multijoint movements of the shoulder and the elbow. When one joint's kinematics was held constant, EMG data showed that there was still variation of muscle activity in the other joint. This evidences that joints interact while performing a movement and movements are adjusted to account for the influence of this interaction (Gribble and Ostry 1999).

Based on the findings of the above research, Ketcham and colleagues (2006) studied the planning and organization of two segment arm movements when both target size and joint coordination were manipulated. They found that young adults functionally planned both segments for all target combinations for the simple but not complex joint movements.

The proposed experiment will be an extension to these studies and aims to understand how changing amplitude and complexity of joint coordination affect the planning and organization of two segment movements. This project will elucidate whether movement of different amplitudes influences control differently than changes in target size, when joint involvement is controlled. Aiming movements involved coordinated rotations of the shoulder an elbow on a tabletop. A '*horizontal'* direction was oriented in medio-lateral direction, at 180°. A '*vertical'* direction was oriented in the anterior-posterior direction, at 90°. On either side of the 90° (vertical) direction were '*right-diagonal'* direction at 45°, and a '*left diagonal*' direction at 135°. The four different direction orientations (*Horizontal, Vertical, Right-diagonal, Left-diagonal*) resulted in four distinct coordination patterns of shoulder and elbow motion and therefore varied in terms of required IT regulations. For instance, movements in the right-diagonal (45°) direction are produced using predominately elbow motion, with minor shoulder involvement. Whereas the elbow is rotated by IT when producing movements in the left-diagonal (135°) direction, predominately controlled by shoulder motion. The remaining two directions, vertical (90°) and horizontal (180°) require motion at both the shoulder and elbow joint with distinct patterns of required IT regulation. In the vertical direction the elbow acceleration is due in part to IT; however, MT is used to regulate the IT effect. In the horizontal direction, IT must be almost completely suppressed. Therefore, due to differences in IT regulation requirements, vertical and horizontal joint coordination patterns are considered 'complex'. Right-diagonal and left-diagonal required joint coordination patterns are considered to be relatively ‘simple’ (Dounskaia 2002a; Dounskaia 2002b; Ketcham 2006).

It was thus hypothesized that movement difficulty as defined by movement amplitude would be planned as a functional unit under all conditions excluding conditions where the initial segment had a high index of difficulty. It is also expected that the complexity of joint involvement will further affect the ability of the planning processes to treat the movement as one integrated segment.

CHAPTER II

METHODS

Participants

This study involved 9 right-handed participants, all young adults (21.2yrs.±1.8). Prior to testing all participants read and signed a consent form approved by the local Institutional Review Board. Young adults were recruited from the Texas A&M University campus and given class credit for their participation. They completed a health-history questionnaire as a means of excluding history of movement impairments.

Procedure and apparatus

Participants were seated at a table with chair height adjusted such that when the arm rested on the table both the upper and lower arm was parallel to the table surface. Subjects performed two-segment aiming movements atop a tabletop in the horizontal plane. Both target amplitude and direction were manipulated to yield a total of 8 different target sequences. Four target directions of *right-diagonal* (45°), *left-diagonal* (135°), *vertical* (90°), and *horizontal* (180°) and two target amplitude combinations (short-long: S*L*, long-short: *LS*) were tested in this experiment (Figure 1). Targets were 1 cm in diameter. Distance between targets was varied, 9 cm from starting position to (T1) and another 31cm from T1 to the second target (T2) in the SL case. In the LS case distance between targets was 31 cm from starting position to (T1) and 9 cm from T1 to the second target (T2). Short movements had an ID of 4.17 and long movements had an

ID of 5.95. Thus, the entire movement was held constant at 40 cm in length. At all four directions, 10 trials of each target amplitude combination were performed; thus, a total of 80 trials were collected. The two targets were displayed below a clear tabletop for each trial. The starting position for each subject was individually adjusted to the position of the index finger, when their shoulder was angled at 140° and elbow at 70° (Figure 1).

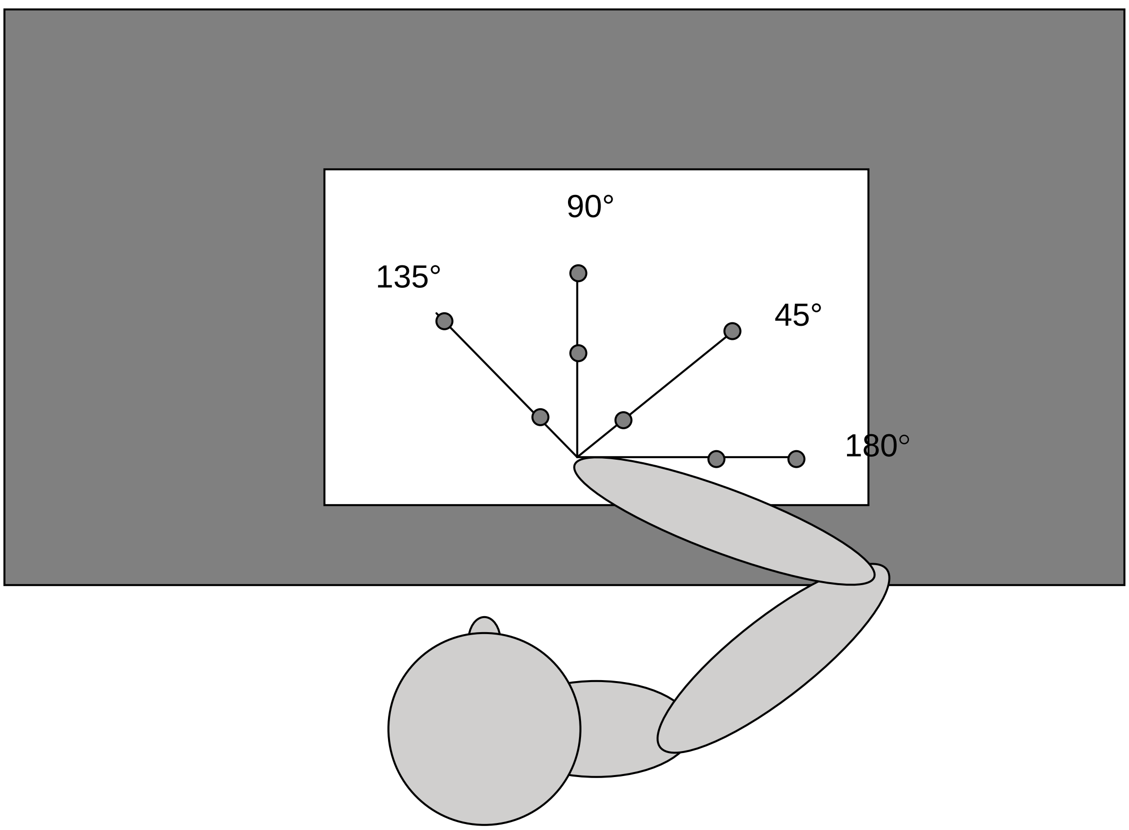


Fig. 1 Setup

<u>Target Distance</u>
Short Distance (9 cm)
Long Distance (41 cm)

The trunk, wrist, and index finger were immobilized such that rotation could only occur at the shoulder and elbow joints. An auditory cue indicated the start of each trial. Subjects were instructed to slide their index finger as fast and accurately as possible, landing in the first target and moving on to the second target. The trial ended when participants stopped in the second target. Movements were recorded using a VICON camera system (120 Hz sampling frequency). Near infrared light emitting diodes were placed on the coracoid processes of shoulders, sternum, proximal upper arm, medial upper arm, elbow, medial lower arm, and index fingernail of the right arm.

Analysis

VICON data were filtered with a 4^{th} order dual pass Butterworth filter and endpoint trajectory analyzed. Velocity was calculated using the first derivative of positional data. Movement onset for each segment was defined as the time at which velocity exceeded 10 mm/s. Movement offset was when velocity at the last sampling point prior to falling below 10 mm/s.

A 4 (Direction) x 2 (Target Amplitude Combination) x 2 (Group) ANOVA with repeated measures was used to analyze the relevant subset of data. Post hoc comparisons (Bonferroni adjusted, $\alpha = .05$) were computed for relevant subsets of data. The Greenhouse-Geisser corrected degrees of freedom were used when sphericity violations occurred.

Measures

For kinematic analysis of the two-segment movement: duration time, peak velocity, and relative time to peak velocity. Duration and kinematic variables were used to determine underlying movement characteristic differences in segment amplitude combinations. Duration is defined as the amount of time from beginning of a movement to ending. Peak velocity (PV) measures are defined as the max velocity acquired during a movement. PV gives important information about the influences of accuracy constraints or subsequent movements on the execution of a particular segment. Relative time to peak velocity is the percentage of the whole movement required to reach the highest velocity during a movement. Analyzing this can give information about how a movement is altered due to the performance requirement of the next segment.

CHAPTER III

RESULTS

Results for total duration are shown below, followed by individual segment results for: peak velocity, relative time to peak velocity.

Duration

Total duration showed that overall SL movements took longer than LS movements ($F(1, 8) = 9.5$, $p < 0.05$) across all direction conditions (Figure 2). Total duration also revealed a significant Direction effect ($F(3, 24) = 4.4$, $p < 0.05$) with right-tilt movements having the longest duration and left tilt being overall the shortest. Long movements were characterized by a longer duration and shorter movements were characterized by shorter durations when performed as the initial segment ($F(1.7, 13.6) = 5.9$, $p < 0.001$) and as the second segment ($F(1, 8) = 215.7$, $p < 0.001$) (Figure 3 A&B). There was a main Direction effect in segments performed initially ($F(1.7, 13.6) = 5.9$, $p < 0.05$). There was a significant difference between the left tilt and horizontal directions in the duration of the initial segment ($p < 0.05$). This suggests some different control in the simple versus complex direction tasks. There were no significant effects for Direction in Segment 2 ($p > 0.05$).

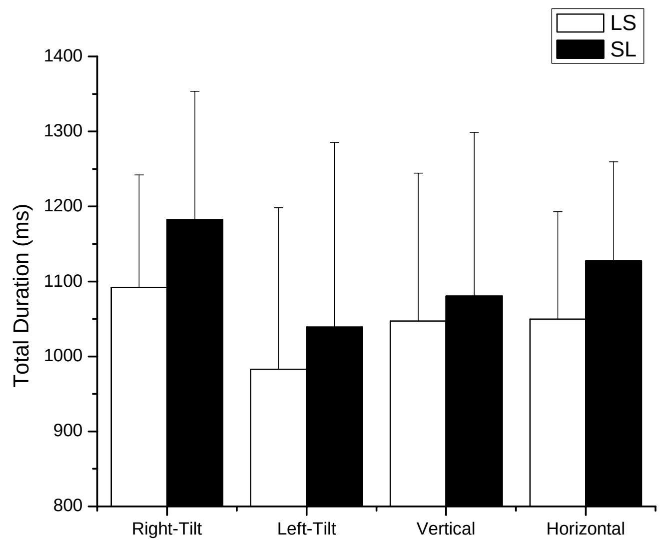
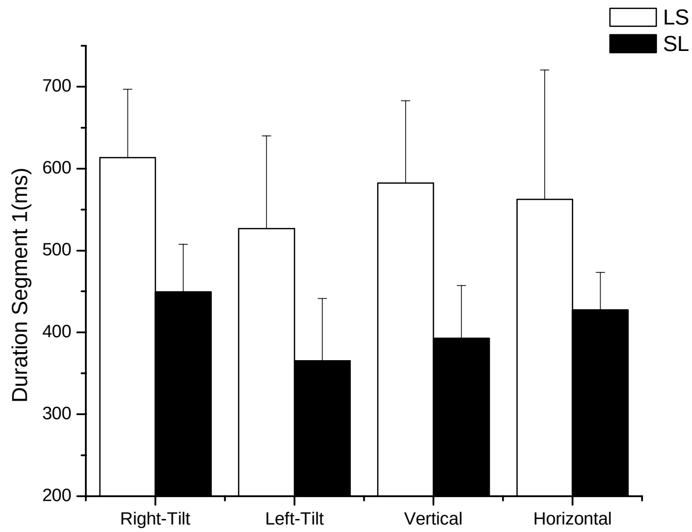
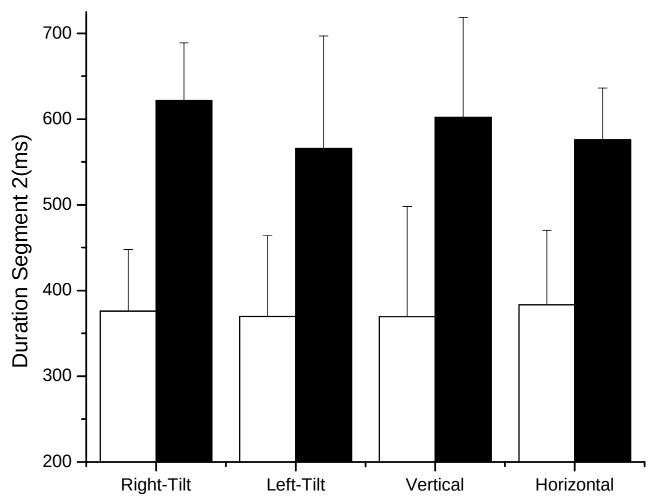


Fig. 2 Total Duration results show that SL movements had a longer Movement Time (MT) than LS movements.



A



B

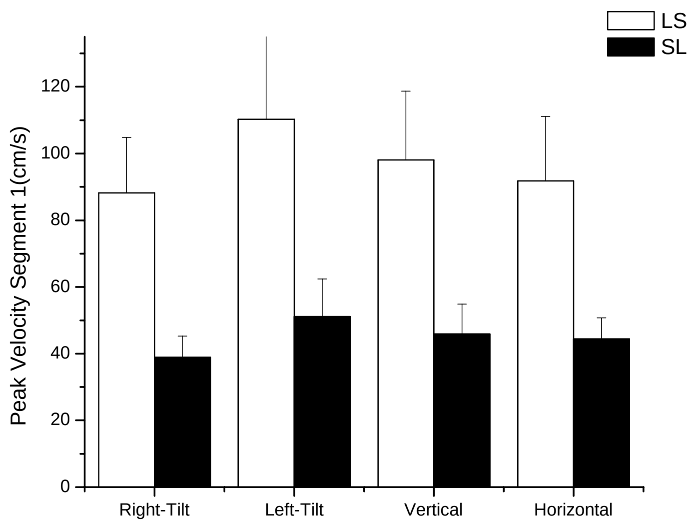
Fig. 3 Long movements had a longer duration time in both Segments 1(**A**) and 2(**B**)

Peak velocity

Peak velocity means for both segments are shown in Figure 4 A&B. Peak velocity was higher in long movements vs. short movements in both the initial segment ($F(1, 8) = 166.4$, $p < 0.001$) and the second segment ($F(1, 9) = 187.4$, $p < 0.001$). Direction effects are seen in initial segments ($F(3, 24) = 6.8$, $p < 0.005$). There was also a significant pairwise difference between vertical (complex movement) and right tilt (simple) movements in segments performed initially ($p < 0.05$). In the second segment there was an interaction between Direction and Distance ($F(1.7, 13.3) = 4.1$, $p < 0.05$). Post-hoc analysis failed to reveal any specific effect of one segment on the other.

Relative Time to Peak Velocity

Relative Time to Peak Velocity revealed a significant Distance effect for both segment 1 ($F(1, 8) = 14.4$, $p < 0.005$) and segment 2 ($F(1, 8) = 55.3$, $p < 0.001$). There were no Direction effects ($p > 0.05$). Post-hoc analysis indicates that subjects spent more time to peak velocity in short segments than for long segments (Figure 5 A&B). This indicates that for a more difficult long movement, subjects spent more time in the deceleration phase.



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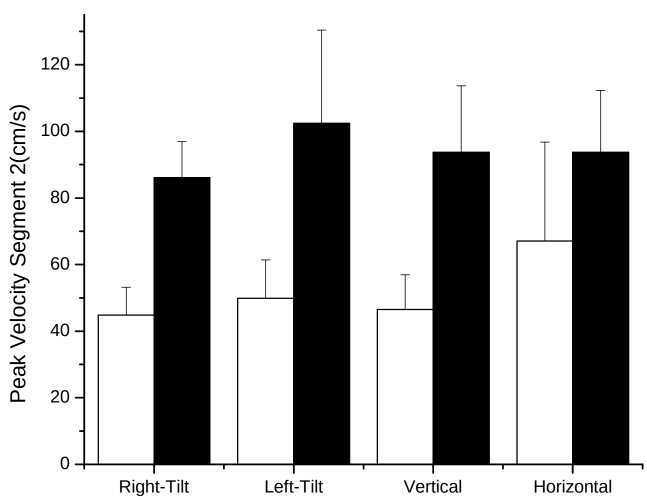
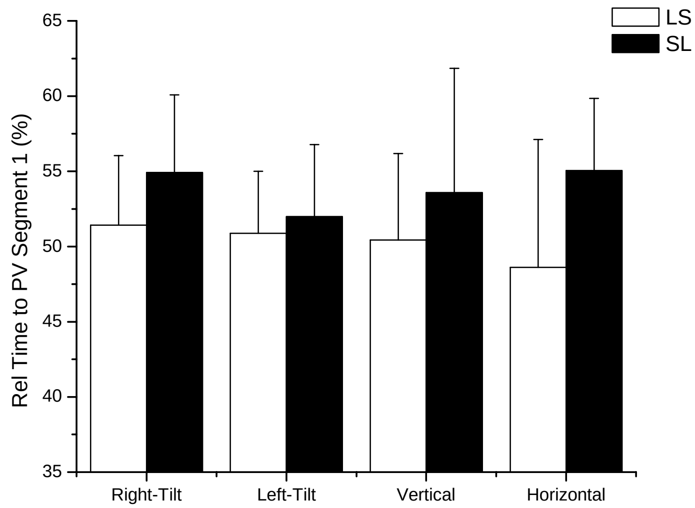


B

Fig. 4 Peak velocity was higher in long movements of the multisegment sequences



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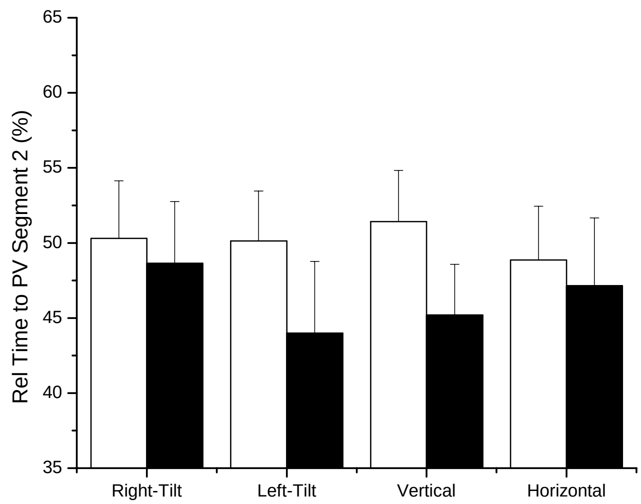

B

Fig. 5 Percentage of time to Peak Velocity was higher for short movements in both the LS and SL condition. Relatively less time to peak velocity was seen in the short segments when performed as the initial segment as compared to short segments performed as the second movement.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The present study examined the planning of two-segment aiming movements as a function of amplitude changes and joint coordination requirements. Previous research expected that when the second segment movement was more difficult, evidenced by a higher ID, the movement of the first was affected. The planning of multisegment movements were planned as a whole movement when the first segment was a low level of difficulty. However, when the ID of the first segment was high, planning was altered. Central planning processes treat the two movements separately, concentrating on the first movement before taking the second into account. The movements were planned in a serial manner (Rand et. al. 1997; Rand et. al. 2000). This study did not find this to be true; showing that less time was spent to peak velocity when the second segment's ID was high. Although joint coordination was found to affect movements based on complexity in previous experiments, in this experiment joint coordination did not specifically relate to planning of movements. In duration and peak velocity of the initial segment, however, differences in the control of simple versus complex movements were seen.

Longer duration times were seen for SL movements than for LS movements. In addition, Long segments had longer duration times than short segments which support previous studies (Fitts 1954).

Peak velocity did not indicate the influence of second segment kinematics on the first segment. However, as was expected, higher peak velocities were seen for long segments compared to short segments. ID of the first movement is high; there are no effects on the second segment (Rand et. al. 1997). This is in part the reason for the differences between short segments and long segments.

To further this, relative time to peak velocity showed that for low ID first movements and high ID second movements, relatively more time was spent to get to peak velocity. Less time was spent in the deceleration of the movement which was contrary to previous studies that show that varying of planning to accommodate a more complex task. This indicates that the movement was not adjusted in order to accommodate to the constraints imposed by the second segments. However, it should be noted that one limitation of our study was that the overall ID of both conditions were the same since we controlled overall distance. Differences might have been seen with two long segments chunked together for example.

Our findings provided no support for the effect of interactive torques on the planning and control of multisegment aiming movements, nor of the influence of one segment on the control of another. Previous studies have found that elbow leading movements are less demanding in terms of IT regulation (Dounskia et al. 2002a). Additionally, direction effects influenced first segments movements. IT regulation was also found to cause two segment movements to be planned as one functional unit, however for greater complexity movements, each segment is planned separately. Our findings do not support this.

Past studies have shown that the slower a movement was performed, the more accuracy was required for that movement (Fitts 1954; Milner and Ijaz 1990; Smyrnis et al. 2000; Thompson et al. 2007). In the current study, more difficult movements were characterized by longer duration times and higher peak velocities. In addition past research has lead to better understanding of mulitsegment aiming movements. When the initial segment has a high level of difficulty and the second a low, the movements seem to be planned separately. However, when the first segment has a low level of difficulty and the second a high, the movements are planned as a functional unit at the beginning of the task. Additionally the second segment ID has an effect on the planning of the initial (Rand et al. 1997; Rand and Stelmach 2000; Rand et al. 2002). This held true in the current study. Relative time spent to peak velocity and relative time in the primary submovement of the initial task was influenced by a longer distance second task.

In conclusion, young adults plan and organize movements as a whole when the first segment was a low ID and the second was a high ID as evidenced by a relative time to peak velocity and relative time spent in the primary submovement. However, when the opposite was true the movement was no longer linked together. Biomechanical factors and IT did not influence the planning of movements differently. A speed accuracy tradeoff was evidenced by longer duration times and higher peak velocities for more difficult movements. This data contributes to the idea that by changing distance in two segment aiming movements, the difficulty of one movement still affects the execution of that subsequent movement. It also supports the notion that the difficulty of the task (accuracy constraints) affects the planning and execution of movements.

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